Mekong River Commission
Basin Development Plan Programme, Phase 2

Assessment of basin-wide development scenarios

List of Technical Notes

Note: Technical note on Fisheries Assessment is being prepared. Only power point presentation is available

Part 4: Impacts on the Tonle Sap great lake ecosystem

Table of contents

Introduction

In this Technical Note results of the assessment of the impacts of the hydrological changes brought about by the Definite Future and 20 Year Plan scenarios on the Tonle Sap ecosystem and the associated species diversity are presented.

In Chapter 2 the unique role of the Tonle Sap Great Lake ecosystem as a ‘fish factory’ for the Lower Mekong fisheries and a habitat for an variety of (rare and endangered) species is described. Emphasis is on migratory fish species and the key features of the Mekong River hydrological system and flood characteristics that are important for the maintenance of theses species and their habitats. The information presented in this chapter has been taken directly from a number of key publications on the Tonle Sap ecosystem, fish migration and spawning patterns and inland fish production. The most important publications used are listed in the Reference list..

Expected impacts of the above mentioned scenarios on the state and functioning of the Tonle Sap system are described in Chapter 3. The impacts mainly pertain to changes in flood conditions in the area: that is changes in total flooded area, changes in ecosystem types being flooded, changes in flood depth and duration and changes in the timing of the flooding. This information has been derived by overlaying an ecosystem/habitat map with flood extension, flood depth and flood duration maps for the various scenarios. The ecosystem/habitat map is a simplification of the MRC (2005) wetland map (level-5).

In the impact assessment predicted changes in water quality of the rivers discharging into the lake are also taken into consideration. These changes result from expected changes in agricultural area and agro-chemical use, as well as in expected changes in waste water discharges in the basin under the Definite Future and 20 Year plan scenario.

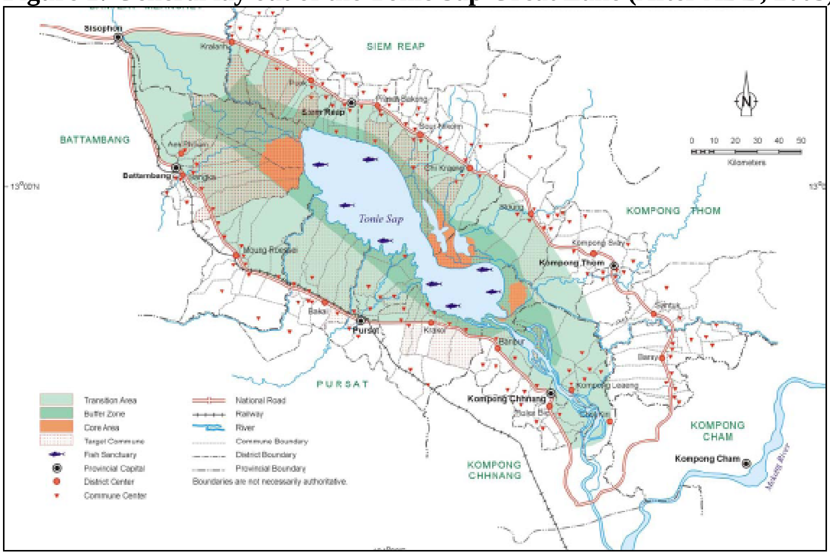
1 The Tonle Sap Great Lake ecosystem and it’s importance for ecology and Lower Mekong fisheries

1.1 Introduction

The Tonle Sap Great Lake is one of the largest freshwater lakes in Southeast Asia. It appears that the lake originated about 5,000 years ago. The unique hydrological regime of Tonle Sap Lake is characterized by an annual inflow of Mekong waters into the lake basin during the wet season, when the water levels in the Mekong fall. At the end of the wet season, the flow reverses and the lake empties again. This hydrological cycle supports and maintains high biodiversity and productivity, particularly fish, plant communities, and wildlife, which are the resource base for the national economy of Cambodia. Nearly half of the Cambodian population depends on the Lake’s resources, about one million of which is fish dependent community. Tonle Sap Lake furthermore plays a vital role in Khmer cultural identity, which is reflected in the traditions, livelihood, festivals, and taste. It is believed that the Khmer Angkor civilization and many temples could not prosper without the rich natural resources of Tonle Sap Lake as sources of wealth. Evidence of cultural influence of Tonle Sap Lake can be found in the bas-reliefs of the Bayon temple. Figure 1 shows the general lay-out of the area (After ADB, 2005).

Recognizing the ecological, economical, and socio-cultural value of the Lake, the Royal Government of Cambodia decided to designate the whole Tonle Sap Lake as Biosphere Reserve under the Man and Biosphere Program of UNESCO in October 1997. Parts of its wetlands are included in the list of Ramsar sites (Ramsar Convention on Wetlands, 1971).

Figure 1: General lay out of the Tonle Sap Great Lake (After ADB, 2005)



1.2 Physical resources

1.2.1 Climate

Cambodia's climate is dominated by the tropical wet and dry monsoons. The southwest monsoon brings the rainy season from mid-May to mid-September or early October, while the northeast monsoon’s flow of drier and cooler air lasts from early November to March. Temperatures are fairly uniform at around 25°C throughout the Tonle Sap Basin area. Average annual rainfall is between 1,300 and 1,900 millimeters, with the largest amounts in the southeast.

1.2.2 Topography and soil

The Tonle Sap Lake is surrounded by a rather flat floodplain. The soils are mainly developed in unconsolidated alluvial deposits, comprising clay, silt, sand, and gravel.

1.2.3 Groundwater

Groundwater depth in the area varies considerably. The water table changes with rainfall, specific local geomorphologic conditions, and the distance to the permanent water of the Tonle Sap Lake. Manganese is reported to be found in the groundwater in concentrations that might cause some consumer inconvenience (e.g., staining of laundry and sanitary ware, taste), though it is not believed to have any negative health effects. Although arsenic concentrations are found in the groundwater throughout Cambodia, they commonly do not pose a problem.

1.2.4 Surface water

The Tonle Sap Lake is connected to the Mekong River through the 100 km long Tonle Sap River. Fifty seven percent of the water in the Tonle Sap Lake comes from the Mekong River. During an average wet season, about 52 percent comes in directly through the Tonle Sap River, and 5 percent flows overland through the floodplain from the Mekong. Another 30 percent comes from rivers that flow directly into the lake and about 13 percent comes from rainfall over the lake itself.

The annual ‘flood pulse’, the cyclical changes between high and low water levels, is crucial in maintaining this highly productive system that has adapted to the exceptionally high natural variability of the lake level. Between the dry and the wet season the volume of the lake ranges from about 1.3 km^3 up to 75 km^3, its surface area varies from 2,500 km^2 up to about 15,000 km^2, and its water level increases from 1.4 m to 10.3 m above sea level.

The quality of surface water shows extreme variations. In the dry season, pollution by human and household waste can be high near densely populated areas.

1.3 Ecological resources

1.3.1 Fisheries and aquatic biology

The flooding of the extensive plain covered with forest and other types of vegetation enables the transfer of terrestrial primary products into the aquatic phase and entry into lake-wide food webs. Sedimentation occurs almost exclusively in the floodplain. The floodplain vegetation plays a crucial role in ecosystem productivity by providing habitats, substrate area, and food for aquatic organisms. Many varieties of fish have commercial value, and more than 100 species are caught regularly. However, about a dozen make up the bulk of the catches, by weight and value. A wide variety of active (seining, lifting, casting) and passive (traps, hooks and line, gillnets) fishing gear and methods are used. Fish behavior (migration, habitat preference, reaction to water quality changes, feeding strategies) is exploited in the fishery. The use of destructive gear and practices (poisoning, electrocution, brush parks, damming, and pumping of channels) are widespread. The importance of the area for fisheries in the entire Lower Mekong Basin is discussed in more detail in Section 6.

Other aquatic animals with direct livelihood significance include water snakes, mollusks, and invertebrates such as shrimp. Water snakes are common in the Tonle Sap ecosystem, and five species commonly are caught and traded. Around the lake, commercial rearing of captive crocodiles is practiced. Indicators suggest that the current use of the Tonle Sap’s natural resources has exceeded optimum ecosystem productivity.

1.3.2 Timber and non-timber forest products

The natural floodplain vegetation is used for the collection of a variety of wood and non-wood forest products. Wood is collected for domestic use, including for (i) fuel wood or charcoal, (ii) construction material, (iii) use in brick kilns, (iv) fish processing (smoking and drying), and (v) the construction of fishing gear. The dominant species include *Barringtonia acutangula*, *Diospyros cambodiana*, *Terminalia cambodiana*, *Gmelina asiatica*, *Ficus heterophylla*, and *Vitex holoadenon*. Non-wood forest products include a wide range of plants used as food, and for medicinal purposes for humans and animals. Lianas (in particular *Combretum trifoliatum*, *Breynia rhamnoides*, *Tetracera sarmentosa*, and *Acacia thailandica*) are collected for furniture and fishing gear production. Other plant products include fruits, seeds, resins, tubers, bark, and mushrooms. Some forest animals and their products are collected, including bee wax and honey. Some larger animals are used as pets (macaques, iguanas, birds), traded, or consumed as food. Birds are hunted for food, pets, and trade. Eggs are collected for consumption. Aquatic plants are collected for human consumption, as feed for farm animals, or for further cultivation (e.g., lotus).

1.3.3 Biodiversity

With the global loss of wetlands, the Tonle Sap Lake and its relatively intact ecosystem processes are exceptionally important for global biodiversity. The species richness of the Tonle Sap ecosystem is only partly known. In a recent inventory, 885 species of floodplain plants and animals were found in the Tonle Sap. However, this does not include, for instance, the 197 species of phytoplankton that have been identified separately. Over 170 species of plants have been identified from the shores around Lake Tonle Sap. Many species are deciduous, shedding leaves with the rising water. Over 140 species of fish have been recorded in the Lake. The lake's productivity is very high and makes a substantial contribution to the annual fish production in Cambodia.

Over 200 species of plants have been found in the inundated forests. Major communities include *Barringtonia acutangula, Elaeocarpus madopetalus* and *Diospyros cambodiana*; floating and emergent herbs including *Brachiaria mutica, Eichornia crassipes, Polygonium barbatum, P. tomentosum* and *Sesbania javanica,* and a diverse mixed scrubland containing over 60 species. The woody species of this forest are often laden with fruits and seeds at the time of inundation, providing food for the 34 species of fruit-eating fish of the Lower Mekong Basin. Over 200 species of fish use this habitat as a feeding, breeding, and nursery ground and it is vitally important for breeding colonies of large water birds.

Lake Tonle Sap's inundated forest is one of the most important breeding sites for large waterbirds in Asia. Species breeding in the forest include the Globally Endangered Greater Adjutant *Leptoptilos dubius* and White-winged Duck *Cairina scutulata*; Globally Vulnerable Spot-billed Pelican *Pelecanus philippensis,* Milky Stork *Mycteria cinerea,* Lesser Adjutant *Leptoptilos javanicus*; and Globally Near-threatened Oriental Darter *Anhinger melanogaster* and Painted Stork *Mycteria leucocephala*. These species are believed to migrate to other wetlands in the Lower Mekong Basin during periods of high water level on Lake Tonle Sap. A more detailed description of the Tonle Sap area is given in a separate background paper.

Seasonally inundated grasslands are common on the floodplains of the Tonle Sap. Close to the water edge, floating or emergent vegetation forms dense mats or stands up to 3 meters tall. As water levels rise, dense mats may dislodge and float, propelled by currents or the wind. The main species include *Achyranthes aquatica, Brachiaria mutica, Eichornia crassipes, Polygonium barbatum* and *Sesbania javanica*. Other plant species found on the upper reaches of the inundated plain include several grasses, including *Echinochloa stagina,* sedges including *Cyperus pilosis, Rhynchospora* sp., and dicotyledons such as *Aeschynomene indica, Impatiens sp., Ludwigia hyssopifolia* and *Nelumbo nucifera* (lotus).

The grasslands support Sarus Crane, White-shouldered Ibis and Greater and Lesser Adjutants. Although, in the Lower Mekong Basin, these areas are greatly disturbed, they do hold more substantial grasslands that other parts of S.E. Asia and thus are a priority for conservation. They are of crucial importance for the Globally Endangered Bengal Florican *Houbaropsis bengalensis*.

The marshes small pools and seasonal wetlands in the area are vital in maintaining breeding stocks of floodplain fish, including air-breathing species (e.g. gouramies, walking catfish), while in the wet season they function as breeding and nursery grounds for many fish species, the black fish. These wetlands are important for almost all water birds in the Lower Mekong Basin, particularly cormorants, Oriental Darter, Spot-billed Pelican, Greater and Lesser Adjutants, Milky Stork, Woolly-necked Stork *Ciconia episcopus*, Black-necked Stork *Ephippiorhynchus asiaticus*, Painted Stork, the Globally Endangered White-shouldered Ibis *Plegadis davisoni,* Glossy Ibis *P. falcinellus*, Black-headed Ibis *Threskiornis melanocephalus*, White-winged Duck, Pallas's Fish Eagle *Haliaeetus leucoryphus*, Grey-headed Fish Eagle, the Globally Vulnerable Masked Finfoot *Heliopais personata*, and the Globally Near-threatened Sarus Crane *Grus antigone*.

The 2004 International Union for Conservation of Nature and Natural Resources (IUCN) Red List of Threatened Species mentions 197 species in Cambodia considered at risk of extinction, endangered, critically endangered, or vulnerable. Many of these are found in the Tonle Sap ecosystem. Of the 197 species mentioned by IUCN, 24 are critically endangered, 39 are endangered, and 53 are vulnerable. In the Tonle Sap ecosystem, 5 critically endangered species (2 fish species, 2 bird species, and the Siamese crocodile) are potentially still present. However, none of these species is endemic to Tonle Sap. As a consequence of 3 decades of unrest, access to the project area has been at times difficult, and a biodiversity inventory of the Tonle Sap ecosystem is far from complete.

In Cambodia, 22 species are classified as data deficient. This could mean that some of these species are threatened, though data are insufficient to assess their condition in full. Several fish species, particularly among those that grow large, are endangered. In its 2004 Red List, IUCN classified the giant Mekong catfish (*Pangasianodon gigas*) as critically endangered. The heavy exploitation of crocodile and the endemic Tonle Sap watersnake (*Enhydris longicauda*) also is of particular conservation concern. The Siamese crocodile (*Crocodylus siamensis*) is critically endangered in the wild, though it is widely bred and kept in captivity. *Orcaella brevirostris*, the freshwater Irriwaddy dolphin that is found in the Mekong, is occasionally also seen in the Tonle Sap Lake. The biodiversity in the Tonle Sap is best known for birds. Of the 104 water bird species that have been recorded in the Tonle Sap, 89 are abundant, while 14 are considered internationally significant. The two core areas of the Tonle Sap Bird Reserve, Prek Toal and Lake Chhmar, have the most endangered species. Prek Toal is the most important breeding area.

1.3.4 ***Land and Crops***

The continuous expansion of agricultural land into the floodplain to address the rising population and low productivity of paddy fields has come at the expense of the natural flooded forest vegetation. The competition between the natural assets of flooded forest and rice and other agriculture crops is increasingly undermining the productivity of the Tonle Sap ecosystem. The foreshore of the Tonle Sap's permanent lake and the river banks provide land, even only seasonally, to the landless poor, who also benefit from being in the vicinity of water for their crops.

1.3.5 ***Livestock***

Livestock is important for the livelihood of many people. Pigs are held widely in floating villages and throughout the floodplain. Cattle provide traction for rice farmers, and flooded forest is burned in places to promote the growth of grass for cattle grazing. Even the poorer households can afford ducks and chicken. Ducks also generate income through their use in pest control in rice fields.

1.4 Economic development

Most of the activities in the project area are based on fisheries or agriculture. Fish processing is widespread, while agriculture focuses on rice production in most places. Infrastructure facilities are largely absent, particularly in the floating or stilted villages. The few access roads are mostly in poor condition. Although ports and landing sites lack basic infrastructure, they contribute effectively to livelihood generation. The lake is used for transportation of people and goods, including petroleum products and fish. Most of the people transported are foreign tourists. Low water levels in the dry season limit the size and traffic of boats.

1.5 Social and cultural resources

More than 1.2 million people in the Tonle Sap area depend on fishing for their livelihood. People typically live in villages, grouped in communes. Many fisher folk are highly mobile, migrating within the floodplain and lake to find fishing opportunities. The Tonle Sap fish and floodplain resources are also part of the livelihood strategies for many people living outside the project area. The distribution and quality of health and education facilities vary. Both are lacking in lake-based communities. The historic temple complex of Angkor Wat, located in the area, is an important tourist attraction. Buildings and features of archaeological and historical significance (e.g., Khmer Empire era temples and shell mounds) are scattered throughout the project area.

1.6 Importance of the Tonle Sap wetland system for fisheries

Cambodia has the world's most productive inland fishery. A single hectare of floodplain can produce up to 230 kilograms of fish a year. In terms of value, the overall fishing sector accounts for 10 to 12 percent of gross domestic product (GDP) and contributes more to income, jobs and food security than in any other country. The inland fisheries has an annual catch conservatively estimated at about 400,000 tons. Tonle Sap fisheries account for almost two-thirds of the total catch in Cambodia. In 2006, the Inland Fisheries Research and Development Institute of the Fisheries Administration estimated the value of fisheries and other aquatic resources of the Tonle Sap Lake conservatively at $233 million a year (Baran et al., 2007).

1.6.1 Relationship between fish production/catches and flood characteristics

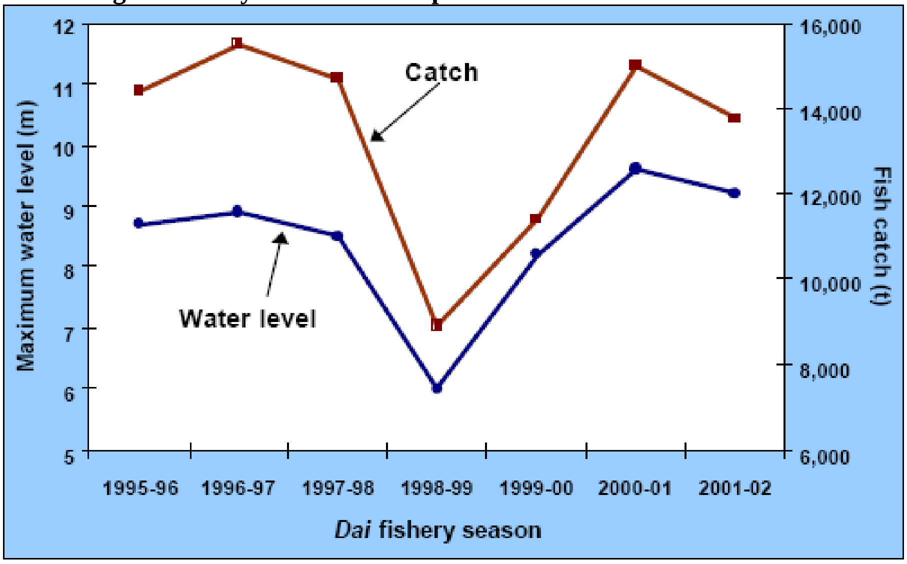
Based on literature on other large river systems elsewhere in the world Baran et al. (E. Baran, N. van Zalinge, Ngor Peng Sun, Floods, floodplains and fish production in the Mekong Basin: present and past trends, MRC miscellaneous publications, not dated) identified a number of factors that determine fish production in the Mekong Basin. They are discussed below:

(a) Water level

The correlation between the *total catch* and the river discharge in the same year has been extensively documented for large river systems around the world. It has also been shown more specifically that catches could be strongly related to the high-water flood regime at the beginning of each season, and that fish grow more quickly when flood levels are higher.

Also for the Lower Mekong it has been shown that higher floods directly result in higher fish production. Although many factors are involved, higher floods produce larger amount of fish and keep a number of important habitats viable. Observations on the bag-net (Dai) fishery for migrating fish in the Tonle Sap River during 1995–2002 indicate that year-to-year variations in maximum Mekong River flood levels and related Tonle Sap floodplain inundation strongly affect the fish yield, see figure 2.

Figure 2: Relationship between the maximum flood level of the season and the fish catch of the Dai or Bag net fishery in the Tonle Sap River.



High fish yields in years with high floods is explained by a number of factors. Firstly spawning success of fishes is related to available spawning grounds: higher floods inundate larger floodplain areas, so creating larger spawning areas. Secondly, a high flood also means that fishing activities are dispersed more evenly over larger areas giving better possibilities for young fishes to survive. The above stated is not valid for all fish species: the fishing lot catch of snakehead (*Channa micropeltes*) was highest one year after a high flood (Van Zalinge et al. 2003).

Other factors of importance are the sediment concentrations of the floodwater and the dissolved oxygen conditions. Sediments carried by the Mekong waters to the Tonle Sap Lake bring in the essential nutrients that enter into the lake's food webs. The higher the flood the more sediment is brought in. This leads to improved survival and growth of fish and hence to higher fishery yields (see also Section 6.1.6).

(b) Duration of the flood

A longer period of flood provides a longer growth period for fishes, and therefore a higher yield. This strong correlation between the annual fish production and the duration of the flood has been clearly demonstrated for many river systems. However, as the process is linked to organic matter decay and nutrient release, the relationship seems to be asymptotic, a plateau being reached after a certain duration.

(c) Timing of the flood

Most tropical fish species release eggs just before or during the flood, which results in their spreading into floodplains. In the Mekong River, rising waters trigger spawning in adults of many species such as Pangasiids and juveniles drift towards the Tonle Sap system where they grow. Timing of the flood and duration of the flood season during which the juveniles can grow are therefore two parameters that will influence the total production (see also Section 7).

Delays in the onset of the flood will result in delays in the arrival of oxygen-rich waters. Dissolved oxygen levels in Tonle Sap water generally decline during dry season, until the inflow of oxygen-rich water at the beginning of flood season. While fish may swim to more oxygenated waters, eggs and larvae are unable to move and may be adversely affected if the arrival of the flood is delayed. Flow changes also have an impact on the drift of fish larvae and juveniles.

(d) Regularity of flooding

After early rainfalls and river level rise have prompted migration and spawning, small drought periods can cause massive mortality of eggs, fish larvae and fry as well as amphibians. Sticky fish eggs can become suddenly exposed on vegetation, while larvae and juveniles can get killed as the water recedes and small ponds dry up. This factor has scarcely been mentioned in the literature, but sometimes happens in the Tonle Sap region where it can result in massive mortality.

(e) Characteristics of the flooded zone

For fishes, floodplains are favorable as a feeding zone (release of nutrients, primary production and detritus- based food chain), and because they provide shelter to juveniles against predation (shallow water, flooded vegetation). The importance of different flood plain habitats for the ecosystems functioning is partly unknown, but the diversity of food resources and habitats allows multiple strategies, species, sizes, stages and life cycle strategies. Flooded forests are essential in providing shelter and living habitats for large variety of biota, but on the other hand shrub and grass land provides often the largest variety of biodiversity. Grass land is obviously playing a major role in nutrient cycling and supports a high fish production.

(f) Physical/chemical conditions

The quality of flood waters has an impact on the flood plain ecosystem e.g. by bringing sediments and nutrients to the system. Nutrient bearing sediment is important for primary production driving the fish growth. Changes in the sediment load can cause major changes in the fish production.

In the Tonle Sap area, sediments are largely being trapped at the interface between the oxygen-rich waters of the lake and rivers and the oxygen-poor waters of the floodplain, giving rise to a rich riparian vegetation of tall trees. The waters above the floodplain are much clearer than the lake waters, as nearly all sediments have been filtered out.

According to Van Zalinge (2003) this explains why the catch per hectare appears to be stable no matter whether natural habitats or agricultural lands are flooded. The biological productivity is derived from the sediments in the waters of the lake, rivers and especially their border areas and not from the extensive floodplains themselves. The sediments contain the nutrients needed by the phytoplankton. Phytoplankton blooms do not occur in the lake, because of intensive grazing by zooplankton and fish.

Oxygen conditions obviously affect where fish can live and reproduce and how different species have developed strategies for avoiding unfavorable conditions. Floodplains are by and large oxygen poor environments. Because of oxygen transport and dispersion, border areas between the well oxygenated lake proper and tributaries and floodplains have more favorable oxygen conditions than areas deeper in the floodplains. Open areas inside the floodplains such as lakes and fields offer better oxygen environments and safety zones for fish. Flow can transport large masses of anoxic water both in the horizontal and vertical direction and trap or kill fish in these limited areas. One explanation for the observed fish deaths may be the anoxic water inflow.

1.7 Fish migration

1.7.1 ***Introduction***

The importance of migratory behavior among Mekong River fishes has been acknowledged for long, many economically important fish species are known to be highly migratory. Some species undertake longitudinal migrations, while others make only localized and lateral migrations. Longitudinal migratory fish species begin to spawn in the Mekong River at the beginning of the rainy season (May-August). Fish eggs and fry are carried by the current and swept into the floodplain areas around the Tonle Sap Great Lake and the areas south of Phnom Penh. When the flood recedes, most of fish species migrate to deeper waters in the lakes, rivers or tributaries (lateral migration), but many species will undertake longer migrations (longitudinal migrations) to the Mekong River

Based on their migration behavior two groups of fish are distinguished: white fish and black fish. When floodplains drain at the end of the wet season, water remains in lakes and scattered depressions, which continue to shrink in size and number during the dry season. Floodplain water bodies become hot, oxygen is depleted and food and shelter diminish, with many ponds drying-out completely. So the fish, which feed and grow on flooded areas must either return to the river as the waters recede, or remain and endure the poor conditions on the floodplain.

Species which leave flooded areas and return to rivers are referred to as longitudinal migrants or ‘white fishes’, as they spend most of their lives in turbid (white) river water. Most white-fish species migrate into flooded areas during the monsoon season and migrate over long distances to dry-season refuges at the end of the flood season. Representatives of this group are some of the cyprinids, such as *Cyclocheilichthys enoplos* (Soldier river barb or Chhkok) and *Cirrhinus microlepis* (Small mud carp or Prul/Kralang), as well as the river catfishes of the family Pangasiidae.

The species of fish which remain in lakes and swamps on the floodplain are known as lateral migrants or ‘black fishes’, as they spend their lives in relatively clear water that is tea-colored by chemicals dissolved from floodplain vegetation. Decomposition of vegetation causes floodplain water to be acidic and depleted in oxygen, stresses which black fishes can tolerate. Most black fishes can breathe air, while many species can survive out of the water for long periods, and most can move overland in search of new water bodies. A few species can bury themselves deep in the mud and wait until the next flood. Many black fishes are used in aquaculture and are transported alive to markets. They are normally referred to as non-migratory, although they perform short seasonal movements between permanent and seasonal water bodies. Examples of black-fish species in the Mekong are the climbing perch (*Anabas testudineus*), the clarias catfishes (e.g. *Clarias batrachus*) and the striped snakehead (*Channa striata*).

An additional group, intermediate between black-fishes and white-fishes is formed by the so-called greyfish. Species of this group undertake only short migrations between floodplains and adjacent rivers and/or between permanent and seasonal water bodies within the floodplain.

1.7.2 Spawning habitats

Spawning habitats are generally believed to be associated with either rapids and deep pools of the Mekong mainstream and tributaries or with floodplains (e.g. among certain types of vegetation, depending on species). River channel habitats are, for example, used as spawning habitats by most of the large species of pangasiid catfishes and some large cyprinids such as *Cyclocheilichthys enoplos*, *Cirrhinus microlepis*, and *Catlocarpio siamensis*. Floodplain habitats are used as spawning habitats mainly by black-fish species.

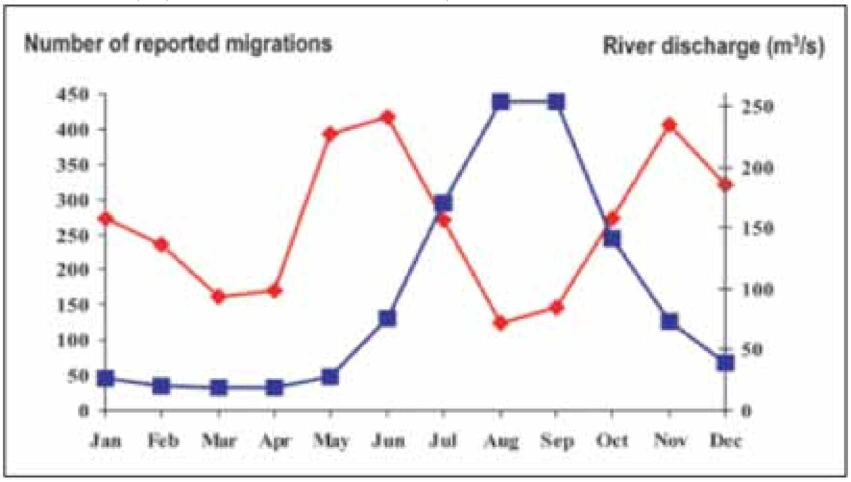
Many species that spawn in river channels in the open-water column rely on particular hydrological conditions to distribute the offspring (eggs and/or larvae) to downstream rearing habitats. Information on spawning habitats for migratory species in the river channels of the Mekong Basin is scarce. Only for very few species, spawning habits are well described. For many species, in particular for deep-water mainstream spawners such as the river catfish species, spawning is virtually impossible to observe directly. Information about spawning has been obtained indirectly from observations of ripe eggs in fishes

For fishes that spawn in main river channels, spawning is believed to occur in stretches where there are many rapids and deep pools, e.g. (1) the Kratie - Khone Falls stretch; (2) the Khone Falls to Khammouan/Nakhon Phanom stretch; and (3) from the mouth of the Loei River to Bokeo/Chiang Khong. The Kratie-Khone Falls stretch and the stretch from the Loei River to Luang Prabang are particularly important for spawning.

1.7.3 Fish migration and hydrology

There is a clear relationship between fish life cycles, fish habitats, and hydrology. Migrating fishes respond to hydrological changes and use hydrological events as triggers for the timing of their migrations. This is illustrated in the figure below, where peak migration periods are correlated with the annual hydrological cycle. Most species migrate at the start of the annual flood and return at the end of the flood, producing the two peaks shown in the figure.

Figure 3: Relationship between migratory activity levels and water discharge in the Lower Mekong Basin. Blue Line: average monthly discharge (m^3/sec) of the Mekong River at Pakse, Red Line: number of migrations reported (based on 50 species from 51 sites along the Mekong mainstream). (After Poulsen et al, 2002)



Also, the spawning season is tuned according to river hydrology, and almost all species spawn at the onset of the monsoon season. Only a few species, spawn during the dry season.

1.7.4 Major migration systems in the Mekong

Different species have developed different life strategies to cope with the environmental circumstances, however, generalizations can be made, e.g. on migratory patterns. Three main migration systems associated with the lower Mekong River mainstream have been identified. These three systems are called the Lower Mekong Migration System, the Middle Mekong Migration System, and the Upper Mekong Migration System. Although these different systems are inter-connected and, for many species, overlapping, the Lower Mekong Migration System is the most important system for the Tonle Sap fisheries.

The Lower Mekong Migration System covers the stretch from the Khone Falls downstream to southern Cambodia, including the Tonle Sap system, and the Mekong Delta in Viet Nam. The migration is driven by the spatial and temporal separation of flood-season feeding and rearing habitats in the south with dry-season refuge habitats in the north. The rise in water levels at the beginning of the flood season triggers many migrating fishes to move from the dry season habitats just below the Khone Falls, e.g. in deep pools along the Kratie - Stung Treng stretch, towards the floodplain habitats in southern Cambodia and the Mekong Delta in Viet Nam. Here they spend the flood season feeding in the fertile floodplain habitats. Some species spawn on, or near the floodplain, whereas others spawn far upstream, i.e. above Kratie, and rely on the water current to bring offspring to the floodplain rearing areas. The Tonle Sap Great Lake system is one of the key factors for the integrity of this system.

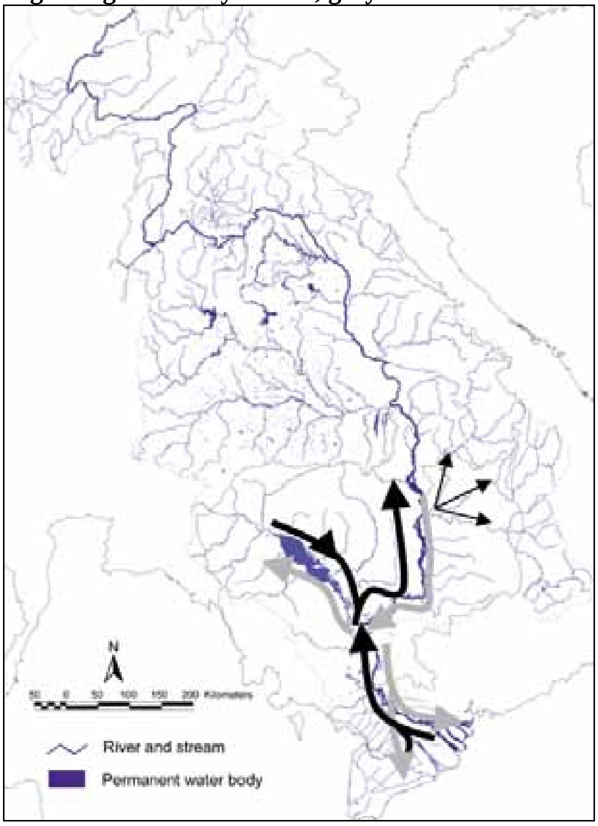
As a result of increasing water discharge from the Mekong River at the onset of the flood season, the water current of the Tonle Sap River changes its direction, flowing from the Mekong into the Tonle Sap River and towards the Great Lake. This enables fish larvae and juveniles to enter the Tonle Sap from the Mekong by drifting with the flow. Together with the floodplains of the Mekong Delta in south Cambodia and Viet Nam, these floodplains are the main 'fish factories' of the lower basin.

An important group of species, which undertakes this type of migration, belongs to the genus *Henicorhynchus*. In terms of fisheries output, these fishes are among the most important of the Lower Mekong. For example, in the Tonle Sap River Dai fishery, species of the genus *Henicorhynchus* account for 40 percent of the total annual catch. Larger species, such as *Catlocarpio siamensis*, *Cirrhinus microlepis*, *Cyclocheilichthys enoplos*, and *Probarbus jullieni*, as well as several members of the family Pangasiidae, also participate in this migration system.

The Sesan tributary system (including the Sekong and Srepok Rivers) deserves special attention here. This important tributary system is intimately linked with the Lower Mekong Migration System, as evidenced by many species such as *Henicorhynchus* sp. and *Probarbus jullieni* extending their migration routes from the Mekong River mainstream into the Sesan tributary system. In addition, the

Sesan tributary system also appears to contain its own migration system. Many of the species (e.g. all the species mentioned above) are believed to spawn within the Mekong mainstream in the upper stretches of the system (from Kratie to the Khone Falls, and beyond) at the beginning of the flood season in May-June. Eggs and larvae subsequently drift downstream with the current to reach the floodplain feeding habitats in southern Cambodia and Viet Nam. The main characteristics of the Lower Mekong Migration System are shown in Figure 4.

Figure 4: The Lower Mekong Migration System. Black arrows indicate migrations at the beginning of the dry season, grey arrows indicate migration at the beginning of the flood season



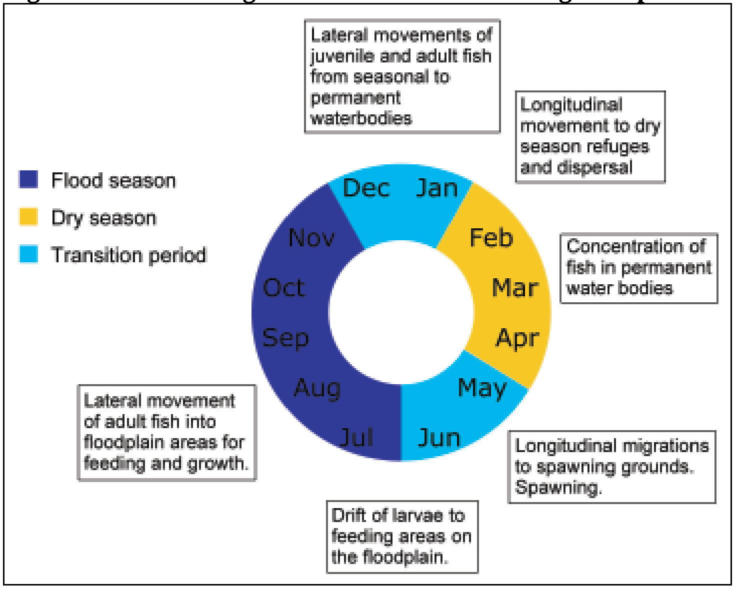
The importance of drifting larvae and juveniles has been documented through intensive sampling of larvae fisheries in the Mekong Delta in Viet Nam. During a sampling period of only 45 days in June-July 1999 127 species were identified from the larvae and juvenile drift.

A general 'migration calendar', as it is valid for an average year and the 'average Mekong fish species is given in Figure 5 after Poulsen et al (2004). Triggers for initiation of migrations are not well understood, although it is generally assumed that increased discharge in itself is a main trigger for migrations: fish typically start to migrate upstream to spawning grounds when the water level starts to increase, spawning while the water level is still increasing to ensure that the current brings eggs and larvae into nursery areas on the floodplain further downstream.

After spawning, the adult fish also move into the flooded areas. During the flood season the fish feed intensively in the flood zone, growing and building up fat layers for the following dry season, when food is scarce.

As the water level starts to drop and the floodplain dries, most fish seek refuge in permanent water bodies, mainly in deeper parts of the main river channel. Fish following this pattern thus utilize three distinct habitats (spawning grounds, feeding habitats and dry season refuges).

Figure 5: General migration calendar for Mekong fish species



1.7.5 Key issues for the maintenance of the Tonle Sap/Lower Mekong fisheries

Although emphasis is on issues related to migratory fishes, the issues are equally relevant for all fish species and indeed for the ecosystem as a whole. Basically, the most important issue in relation to the ecological functioning of the Mekong River from the point of view of migratory fishes is that critical habitats are maintained in time and space. This includes the maintenance of connectivity between them, i.e. through migration corridors. The annual hydrological pattern, including its role in the creation of seasonal floodplain habitats, as well as its role as a distributor of fish larvae and juveniles through passive drift, is of a high importance.

The following key ecological attributes for migratory species are identified:

Dry season refuge habitats	Deep pools in the Kratie-Stung Treng stretch of the Mekong mainstream. These habitats are extremely important for recruitment for the entire lower Mekong Basin, including floodplains in southern Cambodia (including the Tonle Sap Great Lake System) and the Mekong Delta in Viet Nam.
Flood season feeding and rearing habitats	Floodplains in the Mekong Delta in Viet Nam, in southern Cambodia, and in the Tonle Sap system. These habitats support the major part of Mekong fisheries.
Spawning habitats	Rapids and deep pool systems in the Kratie - Khone Falls, and in the Sesan catchment. Floodplain habitats in the south (e.g. flooded forests associated with the Great Lake).
Migration routes	The Mekong River from Kratie - Stung Treng to southern Cambodia and the Mekong Delta in Viet Nam. Between the Mekong River and the Tonle Sap River (longitudinal connectivity). Between floodplain habitats and river channels (lateral connectivity). Between the Mekong mainstream and the Sesan sub-catchment (including Sekong and Srepok Rivers).
Hydrology	The annual flood pattern responsible for the inundation of large areas of southern Cambodia (including the Tonle Sap system) and the Mekong Delta is essential for fisheries productivity of the system. The annual reversal of the flow in the Tonle Sap River is essential for ecosystem functioning. If the flow is not reversed (or if reversal is delayed), fish larvae drifting from upstream spawning sites in the Mekong River cannot access the important floodplain habitats of the Tonle Sap System. A delayed flow reversal would also lead to a reduced floodplain area adjacent to the river and lake, and thus, reduced fish production. Changed hydrological parameters e.g. as a result of water management schemes, result in changed flow patterns, which in turn may change

	sedimentation patterns along the river. Examples of this already exist in some tributaries where hydropower dams have been constructed, resulting in sedimentation, and thus in disappearance of deep pool habitats.

The importance of (longitudinal) migratory fish that rely strongly on the ecological connectivity between floodplains and river channels, in the total fish catch is considerably. Van Zalinge et al. (2000) estimate that longitudinal migrants contribute 63% to the catch of the major Tonle Sap fisheries. Poulsen et al. (2002) estimate the contribution to be 48%.

The remaining proportion of the floodplain yield originates from the black-fish species, i.e. species that spend their entire life on the floodplain. However, many black-fishes are predators, including the abundant *Channa* (snakeheads), and it may be assumed that they feed heavily on whitefishes which have moved into their floodplain habitat.

1.8 Conclusions

Based on above review of the literature a number of conclusions can be drawn that are of importance for the impact assessment:

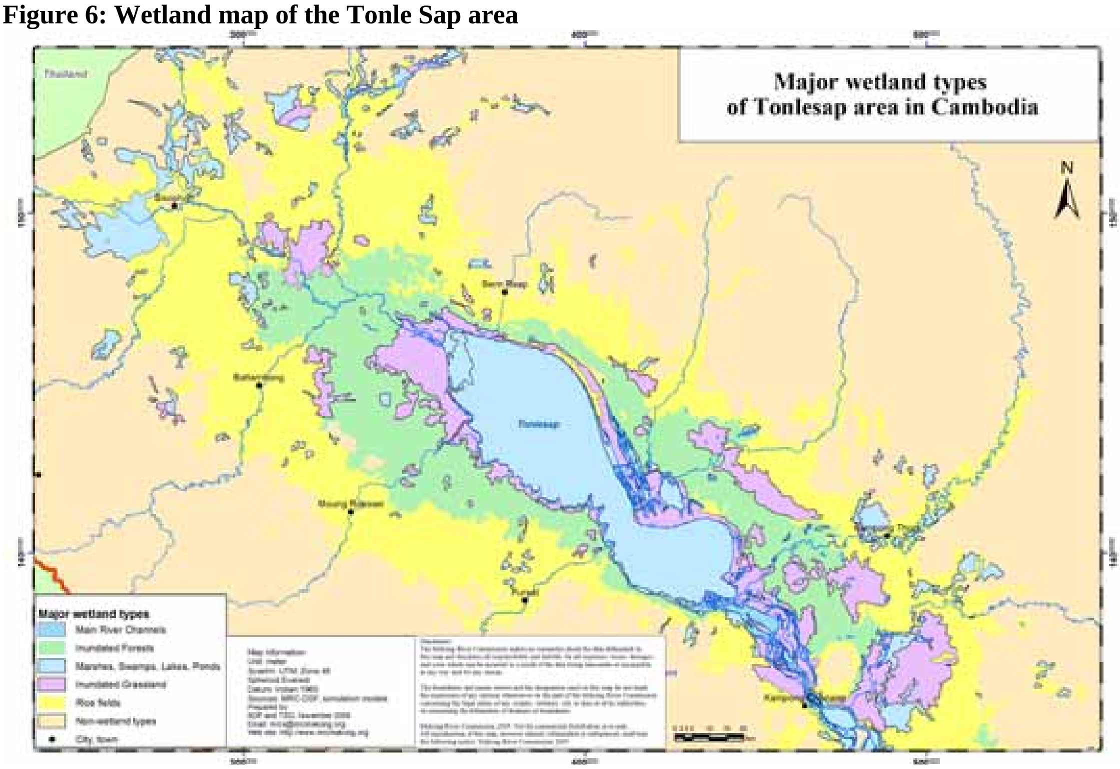
- Tonle Sap Great Lake has a high and unique ecological value, harboring a large number of rare and endangered flora and fauna species;
- The socio - economic value of the Tonle Sap fisheries is extremely high. Longitudinal migrating (between Tonle Sap and the main river) fish make up for probably more than 50% of the yield;
- To maintain ecosystem integrity and ecosystem production, it is important that:
  - fish migration should not be hindered. It is extremely important that free floating eggs and larvae should be allowed to drift into he Tonle Sap area in the period May till mid-July;
  - early flooding of the area is also important because at the end of the dry season the water quality in the remaining refuges may become very poor (anoxic). Inflow of oxygen-rich floodwater has to improve this situation, if not the lateral migrating species (black fish) may not survive;
  - the deeper the flood and the larger the flooded area, the higher the fish production will be;
  - inflow of fine sediments is of crucial importance for the maintenance of the productivity of the system;
  - a variety of floodplain habitats is important for the functioning of the system. Although shrub and grasslands are probably more important than flooded forests, the latter habitat is of crucial importance as well. The impacts of deeper and longer flooding on the flooded forests is not well known at the moment and requires further investigation; and
  - at the start of the dry season (February) longitudinal migration to the dry season refuges should be possible.

2 Impacts of BDP scenarios

2.1 Introduction

Wetland habitats are of crucial importance for the ecological functioning of the Tonle Sap Great Lake ecosystem. Structure and functioning of the wetlands is narrowly linked to the seasonal flooding of the area: as stated in Chapter 2 not only the size of the flooded area is of importance, but also the depth, duration, volume and timing of the flood. In the following section changes in flood characteristics that would result under the Definite Future and 20 Year Plan scenario are described. Figure 6 shows the distribution of the important wetland types over the area.

Figure 6: Wetland map of the Tonle Sap area



2.2 Changes in a biotic conditons

2.2.1 Flooded area

Flooded areas in the Tonle Sap basin under the various scenarios are given in Table 1.

Table 1: Changes in flooded area for a dry , average and wet year under the various scenarios

	Dry Year	Average Year	Wet Year
Baseline	1,175,410	1,286,951	1,484,170
Definite Future	1,130,244	1,247,678	1,464,257
Change from Baseline (ha)	-45166	-39273	-19913
Change from Baseline (%)	-3.8	-3.1	-1.3
20 Year Plan	1,074,027	1,229,128	1,461,536
Change from Definite Future (ha)	-56,217	-18,550	-2,721
Change from Definite Future (%)	-5.0	-1.5	-0.2
Change from Baseline (ha)	-101,382	-57,823	-22,634
Change from Baseline (%)	-8.6	-4.5	-1.5

The table shows that, when comparing the 20 Year plan scenario with the Baseline, the total flooded area in the Tonle sap area will reduce with some 4.5%. Over 3% of this reduction is already the result under the Definite Future scenario. Reductions are larger in a dry year (8.6 %) and less in a wet year (1.5%).

Table 2 shows that the reduction in flooded area of valuable wetland types, in an average hydrological year, is limited to around 1% for the flooded forests and marshes, and just over 3% for the inundated grasslands, the area of flooded rice fields is reduced by some 18%. More than half of these changes already result under the Definite Future scenario.

Table 2: Areas of valuable wetland types that will not flood anymore in an average hydrological year under the Definite Future and 20 Year Plan scenario

	Inundated Forest	Marshes	Inundated grasslands	Rice Fields
Baseline	451,454	310,577	275,380	230,500
Definite Future	448,721	308,304	269,691	202,007
Change from Baseline (ha)	-2733	-2273	-5689	-28493
Change from Baseline (%)	-0.6	-0.7	-2.1	-12.4
20 Year Plan	446,452	307,361	266,682	189,717
Change from Definite Future (ha)	-2,269	-943	-3,009	-12,290
Change from Definite Future (%)	-0.5	-0.3	-1.1	-6.1
Change from Baseline (ha)	-5,002	-3,216	-8,698	-40,784
Change from Baseline (%)	-1.1	-1.0	-3.2	-17.7

In a dry hydrological year losses are bigger: 5% less forest will be flooded, 2% less marshes and 10% less inundated grasslands. As is to be expected the losses are much more limited in a wet hydrological year: less than 0.5% of the important wetland types will not flood anymore. see tables 3 and 4 for the details.

Table 3: Areas of valuable wetland types that will not flood anymore in a dry hydrological year under the Definite Future and 20 Year Plan scenario

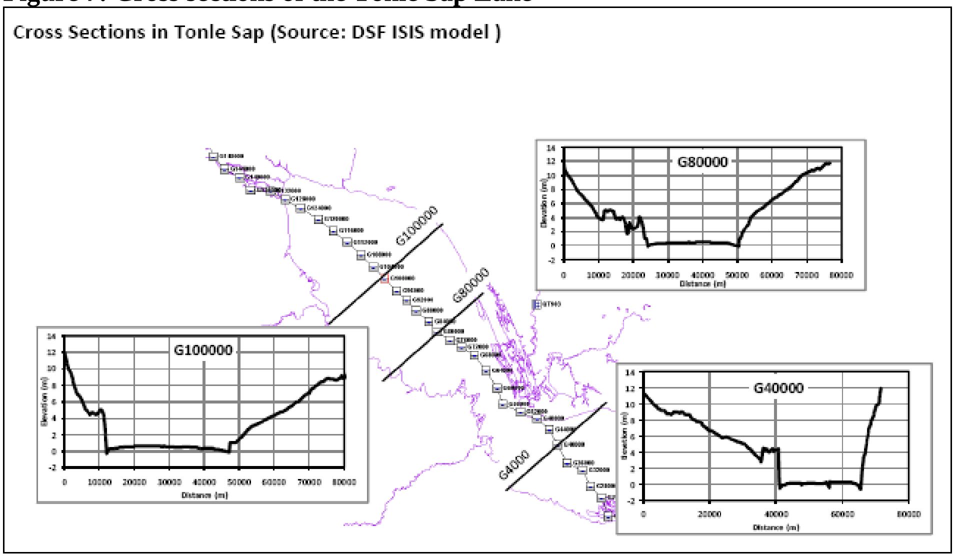
	Inundated Forest	Marshes	Inundated grasslands	Rice Fields
Baseline	431,961	303,383	246,390	175,000
Definite Future	425,097	300,028	236,049	150,426
Change from Baseline (ha)	-6865	-3354	-10342	-24574
Change from Baseline (%)	-1.6	-1.1	-4.2	-14.0
20 Year Plan	408,951	297,999	221,712	126,757
Change from Definite Future (ha)	-16,145	-2,030	-14,336	-23,669
Change from Definite Future (%)	-3.8	-0.7	-6.1	-15.7
Change from Baseline (ha)	-23,010	-5,384	-24,678	-48,243
Change from Baseline (%)	-5.3	-1.8	-10.0	-27.6

Table 4: Areas of valuable wetland types that will not flood anymore in a wet hydrological year under the Definite Future and 20 Year Plan scenario

	Inundated Forest	Marshes	Inundated grasslands	Rice Fields
Baseline	456,824	318,522	287,812	401,939
Definite Future	456,512	317,555	286,642	384,474
Change from Baseline (ha)	-312	-967	-1169	-17465
Change from Baseline (%)	-0.1	-0.3	-0.4	-4.3
20 Year Plan	456,434	317,424	286,429	382,175
Change from Definite Future (ha)	-78	-131	-213	-2,299
Change from Definite Future (%)	0.0	0.0	-0.1	-0.6
Change from Baseline (ha)	-390	-1,098	-1,382	-19,764
Change from Baseline (%)	-0.1	-0.3	-0.5	-4.9

In the dry season average water levels in the Tonle Sap will be higher under the Definite Future and 30 Year Plan scenario as compared to the baseline. Typically the increase will be some 20 cm. However, this will not influence the 'permanent flooded' area around the lake, since the cross section of the lake is such that an increase of water levels in the dry season does not result in an increase in the flooded area, see Figure 7.

Figure 7: Cross sections of the Tonle Sap Lake



2.2.2 Flood depth

Reductions in flood depth under the various scenarios and for the various hydrological years are quite significant. When comparing the Baseline scenario with the 20 Year Plan scenario, it appears that in nearly 98% of the area the reduction of flood depth is just over 0.5 m, see Table 5.

Table 5: Reduction in flood depth (Base Line vs 20 Year Plan), average year

Wetland Types	>0.5m	0.4 - 0.5	0.3 - 0.4	0.2 - 0.3	0.1 - 0.2	<0.1	Total
Inundated forests	446,375	2,956	989	598	560	463	451,941
Marshes, Swamps, Lake, Pond	300,606	3,292	5,620	551	546	735	311,350
Inundated Grassland	269,267	1,819	1,533	1,468	1,326	1,117	276,529
Total	1,016,248	8,067	8,142	2,617	2,431	2,315	1,039,820
Percentage of area	97.7	0.8	0.8	0.3	0.2	0.2	100.0

More detailed analysis shows a somewhat irregular pattern, the deep flooded forest area(>3.0 m) decreases with 40,000 ha (12%). Also the area that if flooded by 0.5 – 1.0 m decreases somewhat, the shallow flooded area (0 – 0.5 m) increases with more than 200%, which is equivalent to an increase in area with nearly 7,000 ha, see Table 6..

Table 6: Flooded forests, change in flood depth under the various scenarios, average year

Flood depth	0 - 0.5 m	0.5 - 1.0 m	1.0 - 3.0 m	> 3.0 m
Baseline	2,920	11,499	101,017	336,018
Definite Future	9,886	8,737	121,398	308,699
Change from Baseline (ha)	6,966	-2,762	20,381	-27,319
Change from Baseline (%)	238.5	-24.0	20.2	-8.1
20 Year Plan	9,895	9,816	131,000	295,741
Change from Definite Future (ha)	9	1,079	9,602	-12,958
Change from Definite Future (%)	0.1	12.3	7.9	-4.2
Change from Baseline (ha)	6,975	-1,683	29,983	-40,277
Change from Baseline (%)	238.8	-14.6	29.7	-12.0

Analysis of the flood maps learnt that when comparing the Baseline scenario with the 20 Year Plan scenario, flood levels in an average year reduce with just over 0.5 m in more the 95% of the forest area. Of this reduction 0.3 to 0.4 m is already the result of the Definite Future scenario.

Inundated grassland show a trend comparable to the forests: a shift from deep flooded to more shallow flooded, see Table 7. In more than 95% of the grassland area the decrease will be just over 0.5 m in an average hydrological year, when the 20 Year Plan is compared with the Baseline. Again, the Definite Future scenario accounts for 0.3 to 0.4 m of this reduction.

Table 7: Inundated grasslands, change in flood depth under the various scenarios, average year

Flood depth	0 - 0.5 m	0.5 - 1.0 m	1.0 - 3.0 m	> 3.0 m
Baseline	6,003	17,284	73,425	178,668
Definite Future	14,193	15,094	67,999	172,406
Change from Baseline (ha)	8,189	-2,190	-5,427	-6,262
Change from Baseline (%)	136.4	-12.7	-7.4	-3.5
20 Year Plan	15,590	15,769	65,049	170,275
Change from Definite Future (ha)	1,397	675	-2,950	-2,131
Change from Definite Future (%)	9.8	4.5	-4.3	-1.2
Change from Baseline (ha)	9,586	-1,515	-8,376	-8,392
Change from Baseline (%)	159.7	-8.8	-11.4	-4.7

Flood depth changes in the marshes are comparable to those in the flooded forest and grassland areas: a decrease with more than 0.5 m in over 99% of the area, again, largely attributable to the Definite Future scenario.

In a dry hydrological year flood depths are less, compare Table 6 with Table 8 and 9. Analysis of the flood maps shows hat reduction of flood depths, going from the Baseline scenario to the 20 Year Plan scenario, is still just over 0.5 m in about 95% of the flooded forest and flooded marsh area, and in 85% of the inundated grassland area. Nearly 10% of the inundated grasslands have a flood depth reduction of 0.4 – 0.5 m.

Table 8: Flooded forests, change in flood depth under the various scenarios, dry year

Flood depth	0 - 0.5 m	0.5 - 1.0 m	1.0 - 3.0 m	> 3.0 m
Baseline	20,115	16,080	195,917	199,849
Definite Future	22,855	20,283	207,771	174,188
Change from Baseline (ha)	2,740	4,202	11,854	-25,661
Change from Baseline (%)	13.6	26.1	6.1	-12.8
20 Year Plan	15,802	43,266	227,882	122,001
Change from Definite Future (ha)	-7,053	22,984	20,111	-52,187

Change from Definite Future (%)	-30.9	113.3	9.7	-30.0
Change from Baseline (ha)	-4,312	27,186	31,965	-77,849
Change from Baseline (%)	-21.4	169.1	16.3	-39.0

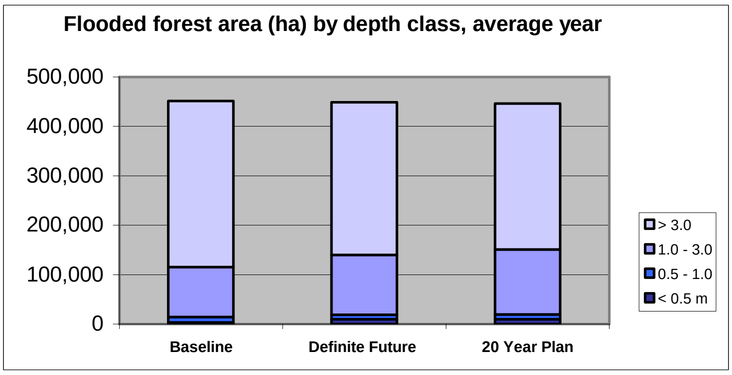
Table 9: Inundated grasslands, change in flood depth under the various scenarios, dry year

Flood depth	0 - 0.5 m	0.5 - 1.0 m	1.0 - 3.0 m	> 3.0 m
Baseline	23,103	17,130	48,723	157,434
Definite Future	23,722	15,934	42,979	153,413
Change from Baseline (ha)	619	-1,196	-5,744	-4,021
Change from Baseline (%)	2.7	-7.0	-11.8	-2.6
20 Year Plan	17,142	19,569	40,423	144,578
Change from Definite Future (ha)	-6,580	3,635	-2,556	-8,835
Change from Definite Future (%)	-27.7	22.8	-5.9	-5.8
Change from Baseline (ha)	-5,961	2,440	-8,300	-12,856
Change from Baseline (%)	-25.8	14.2	-17.0	-8.2

Figures 7 and 8 show the differences in flood depth in the flooded forest areas and inundated grasslands in a dry hydrological year as compared to an average hydrological year.

In a hydrologically wet year, flood depth changes in over 95% of the flooded forest area, the inundated grassland area and the flooded marshes reduce with only 10 to 20 cm between the Baseline scenario and the 20 Year Plan scenario. These changes can be completely attributed to the Definite Future scenario.

Figure 7: Flood depths in the flooded forests in an average (top) and a dry year (bottom)



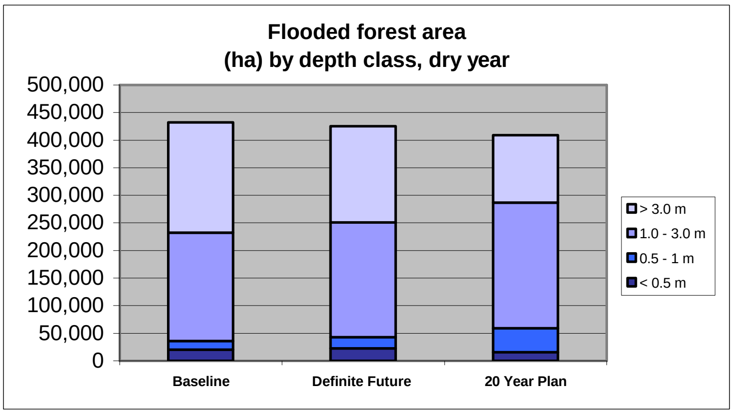
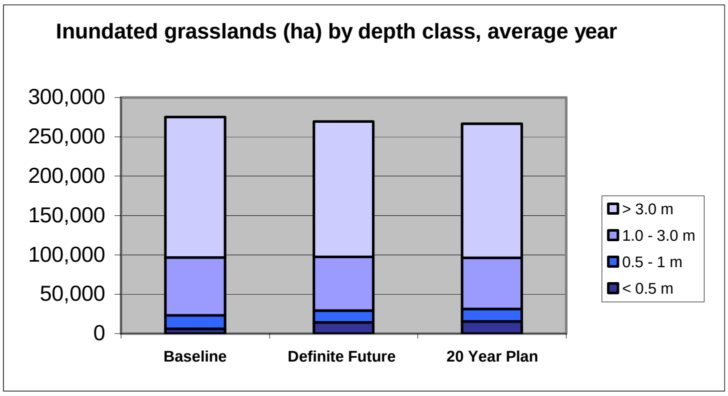
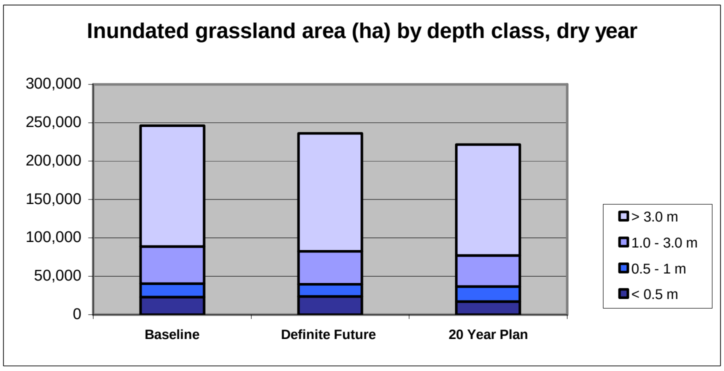


Figure 8: Flood depths in the inundated grasslands in an average (top) and a dry year (bottom





2.2.3 Flood duration

Analysis of food duration maps for the various scenarios show a somewhat more complex pattern of changes than the observed changes in flood depth.

In an average hydrological year, flood duration in 70% of the flooded forest area reduces with less than 2 weeks, going from the Baseline to the 20 Year Plan scenario. Under the Definite Future scenario, 85% of the area experiences a flood duration reduction of less than 2 weeks. The situation is a bit different in a dry hydrological year: flood duration decrease with less than 2 weeks in 39% of the flooded forest area, and with between 2 weeks and 1 month in 56% of the area going from the Baseline scenario to the 20 Year Plan scenario. Under the Definite Future scenario reductions are less than 2 weeks in 93% of the flooded forests. In a wet year flood duration reduction is less than 2 weeks in 95% of the flooded forest area.

Table 10: Changes in flood duration of flooded forests for the various hydrological years, going from the Baseline to the 20 Year Plan scenario

	Decrease in flood duration (month)			Increase in flood duration (month)		
	1.0 - 2.0	0.5 - 1	< 0.5	< 0.5	0.5 - 1	1.0 - 2.0
Average year	3	25	70	0	0	0
Wet year	0	5	95	0	0	0
Dry year	4	56	39	0	0	0

Of the inundated grassland area changes in flood duration are different from those observed in the flooded forest areas: flood duration locally increases. In an average hydrological year 24% experiences a flood duration reduction of less than 2 weeks going from the Baseline scenario to the 20 Year Plan scenario, in 34% of the area, the reduction in flood duration is between 2 weeks and 1 month. However, flood duration increases with up to 1 month in 25% of the inundated grasslands and with even more than 1 month in 7% of the area. In a hydrologically dry year flood duration increases in 32% of the grassland area, again going from the Baseline to the 20 Year Plan. In the remaining area flood duration decreases with on average less than a month. In a hydrologically wet year average flood duration mainly decreases: with less than 2 weeks in 69% of the area, and with 0.5 to 1 month in 14% of the area. In 17% of the grassland area flood duration increases, but with less than 1 month, see Table 11

Table 11: Changes in flood duration of inundated grasslands for the various hydrological years, going from the Baseline to the 20 Year Plan scenario

	Decrease in flood duration (month)			Increase in flood duration (month)		
	1.0 - 2.0	0.5 - 1	< 0.5	< 0.5	0.5 - 1	1.0 - 2.0
Average year	10	34	24	11	14	7
Wet year	0	14	69	11	6	0
Dry year	7	30	31	3	10	19

Flood duration in less than half (42%) of the flooded marshes area reduces with up to 2 months in an average hydrological year, going from the Baseline scenario to the 20 Year Plan scenario. However, in 58% of the area, flood duration increases, generally with less than 1 month (See Table 12). In a dry hydrological year flood duration in over 70% of the flooded marsh area increases, in 44% of the area even with 1 – 2 months. In a wet year there is generally a reduction of flood duration (65% of the area) and changes are generally less than 2 weeks.

Table 12: Changes in flood duration of flooded marshes for the various hydrological years, going from the Baseline to the 20 Year Plan scenario

	Decrease in flood duration (month)			Increase in flood duration (month)		
	1.0 - 2.0	0.5 - 1	< 0.5	< 0.5	0.5 - 1	1.0 - 2.0
Average year	8	16	18	19	30	9
Wet year	2	10	53	20	15	1
Dry year	4	14	11	5	23	44

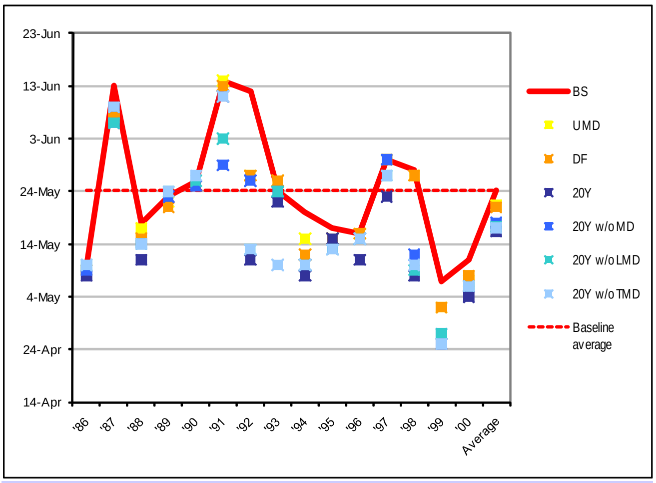
2.2.4 Reverse flow of the Tonle Sap

Flow reversal occurs in the Tonle Sap River when floods rise in the mainstream and levels there exceed those in the Tonle Sap Lake, causing the river to reverse its flow into the lake. As the mainstream floods recede and levels fall there comes a point when the levels in the lake exceed those in the mainstream and normal flows resume. Two analyses have been conducted on flow reversal at the Prek Dam monitoring site. The first is to determine the likely impacts on the timing of when flow reversal occurs and the second is to assess changes in flow volume. As described in Chapter 2 these parameters are of importance for the ecological functioning of the Tonle Sap system and wider LMB.

The dates of when flow reversal occurs have been abstracted for each year for each scenario and averaged. In comparison to the baseline, reversal occurs slightly earlier in each scenario, but only by typically 3 days under both the Definite Future Scenario (within a natural range of +/-19 days) and 20-Year Plan scenario, see Figure 9.

Figure 9: Start date of the flow reversal under the various scenarios

Start date for flow reversal



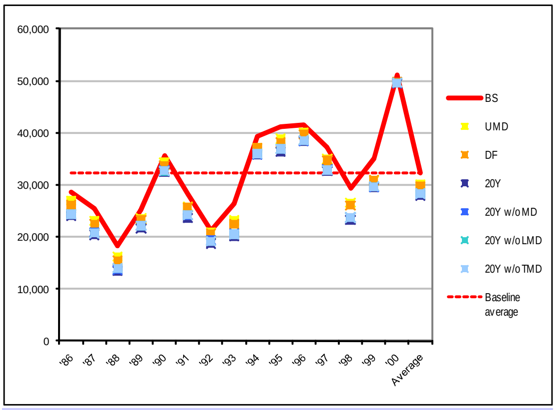
	BS	UMD	DF	20Y	20Y w/o MD	20Y w/o LMD	20Y w/o TMD
Average start date	24-May	21-May	21-May	16-May	18-May	17-May	17-May
Days earlier	0	3	3	8	6	7	7
Max-min start date	38	43	42	47	40	40	47
Range increase (days)	0	5	4	9	2	2	9

Under the 20-year Foreseeable Future Scenario with no or fewer mainstream dams, the flow reversal date advances by between 3 and 8 days on average. In general the scenarios increase the variability of the start date, from +/- 19 days in the baseline up to between +/- 24 and 35 days, again with similar results for both the Definite Future Scenario and 20-year Foreseeable Future Scenario with all mainstream dams.

A similar analysis has been conducted on the average volume of flow that occurs each year during the flow reversal period (see overleaf). The results are that under the Definite Future scenario there is a predicted decrease in flow reversal volume of 8% rising to 13% under the 20 Year Plan scenario, see Figure 10.

Figure 10: Volumes of flow reversal under the various scenarios

Volume of flow reversal MCM



	BS	UMD	DF	20Y	20Y w/o MD	20Y w/o LMD	20Y w/o TMD
Average volume	32,259	30,145	29,740	27,993	28,358	28,339	28,340
Change from BS	0%	-7%	-8%	-13%	-12%	-12%	-12%
Max-min volume	32,950	33,530	34,286	36,065	35,833	35,633	35,631
Range increase (MCM)	0%	2%	4%	9%	9%	8%	8%

The picture that emerges from these calculations is that higher water levels predicted in the mainstream at the end of the dry season will cause flow reversal to occur earlier with a reduction in the inflows to the lake.

Since water levels in the dry season will be about 30 cm higher under the 20 Year Plan scenario as compared to the Baseline scenario, the volume of water in the dry season will increase considerably. With a dry season area of about 260,000 ha, an increase in water level of 20 cm equals an increase in lake volume with about 520 MCM, a considerable addition to the present 1,500 MCM lake volume in an average dry season.

2.2.5 ***Sediment inflow***

According to Carling (2010, Geomorphological Assessment of Basin Development Scenarios), sediment concentrations in the floodwaters downstream Kratie will not significantly change under the Definite Future and 20 Year Plan scenario. This implies, that given the fact that the reverse flow to the Tonle Sap area will reduce with 8 to 13 percent, also the total amount of sediments brought to the system will decrease with between 8 and 13%. Furthermore there will be a very gradual shift towards somewhat coarser sediment, that are less fertile than fine sediments.

2.2.6 ***Water quality***

Under the 20 Year Plan scenario, irrigated rice cropping in the Tonle Sap Basin will increase in area. The use of agro-chemicals (fertilizers, pesticides etc.) will also increase, as will the population in the basin. As a result nutrient loads of the rivers discharging into the lake will increase, see the Technical Note on Water Quality for details. Impacts on the water quality will be biggest in the dry season, when lake volumes and river discharges are lowest.

Dry season rice cropping in the Tonle Sap Basin takes place in the months January, February and March. N losses under the Definite Future scenario are 1280 ton, as compared to 3,745 ton under the 20 Year Plan scenario. P losses are 166 ton (Definite Future) and 506 ton (20 Year Plan) (See Technical Note on Water Quality). Applying a nutrient retention rate of 67% and assuming an average discharge of the Tonle Sap River of 2,000 m^3 over the months of January, February and March. Changes in concentrations are as given in Table 13.

Table 13: Amounts of N and P discharged from the Tonle Sap Basin into the Tonle Sap Lake and discharged via the Tonle Sap River

	Load (ton)		Volume	Concentration (mg/l)	
	N	P	(MCM)	N	P
Present	427	55	15,552	0.027	0.0036
20 Year Plan	1248	169	15,552	0.080	0.0108
Increase	822	113	0	0.053	0.0073

Liljestrom (2007) calculated annual Nitrogen and Phosphorous fluxes at Prek Kdam. The results show that the annual net nitrogen flux (in a hydrological year) ranges between approximately 15,000 ton into the lake to 15,000 ton out of the lake. The annual net phosphorus flux ranges between approximately 1,200 ton into the lake to 1,700 ton out of the lake. The variation and ranges are large and the net fluxes are spread quite evenly over the entire range. The average values of the net fluxes indicate that the lake, on average, acts as a nitrogen sink and as a phosphorus deliverer. It has to be noted that these observations are based on a relatively short observation period: 7 years only.

However, the results on nutrient flux calculations for the Prek Kdam monitoring site suggest that there is great variation in nutrient transportation into and out of the Tonle Sap Lake via the Tonle Sap River. According to the results, the lake acts during some hydrological years as a nutrient sink, and during others as a nutrient source. Nitrogen and phosphorus fluxes further vary independently from each other.

The large variation in the net nutrient fluxes between hydrological years indicates that the nutrient movement and transformation processes are complex. More research is needed on factors that influence and contribute to the lake's nutrient dynamics.

The increase in loads of 800 ton (N) and 100 ton (P) in the dry season is small compared to the annual flux of 15,000 ton (N) and about 1,500 ton (P). Therefore, also given the very large variation of fluxes over the years, increased nutrient loads to the lake are thought not to have significant impacts.

Increased nutrient loads due to population growth are small compared to the increases resulting from agriculture and are therefore not considered further.

Until now there are no signs of any basin significant pollution with herbicides, pesticides and fungicides in the Mekong River's water and sediments: pesticide levels were below detection limits in river water studies conducted between 2003 and 2004 (MRC, 2007). Pesticide applications are low in Cambodia, but expected to increase considerable going from the Definite Future to the 20 Year Plan scenario. However, it is very hard to predict whether or not this will lead to detectable concentrations in the surface water and river sediments. Locally, intensive cultivation may result in concentrations that are above the thresholds values, as is already reported from certain parts of the basin.

2.3 Consequences for the biotic system

Overall changes in the abiotic conditions in the Tonle sap system, going from the Baseline to the 20 Year Plan scenario, can be summarized as follows:

- Reduction of the flooded area with 60,000 ha (4.5 %) in an average year, and as much as 100,000 ha (9%) in a dry year;
- Reduction of the area of flooded forest with 5,000 ha (1.1%) in an average year to 23,000 ha (5.3 %) in a dry year;
- Reduction of the area of inundated grasslands with 8,500 ha (3.2%) in an average year to 25,000 ha (10 %) in a dry year;
- Reduction of the area of flooded marshes with 3,000 ha (1.0%) in an average year to 5,500 ha (1.8 %) in a dry year;
- Reduction of the area of flooded ricefields of 41,000 ha (18%) in an average year and 48,000 ha (28 %) in a dry year;
- Reduction of flood depth of just over 0.5 m in an average and dry year;
- Reduction of flood duration of the flooded forest area with generally less than 2 weeks in an average year, but up to 1 month in a dry year;
- Reduction in flood duration with generally less than 1 month in an average year in 70% of the inundated grassland area, but an increase of flood duration with up to 1 month in 25% of the area. A similar pattern is to be seen in dry years, even with a bit more pronounced increase;
- A reduction of the reverse flow with 8 (Definite Future) to 13% (20 Year Plan);
- Increase of the water level in the dry season with about 20 cm, resulting in a volume increase of 520 MCM, or an increase with some 30%;
- Shift of the flow reversal date of 3 to 8 days (earlier);
- Reduction of sediment inflow in the system of at least 8 to 13%;
- An overall increase in nutrient (and other agro-chemical) inflow into the lake; and
- Blockage of the migration paths (by mainstream dams under the 20 Year Plan scenario) of a large number of ecologically and commercially important fish species.

Considered separately, most of above changes could be interpreted as fairly small, however, the cumulative impact on the Tonle Sap ecosystem could be very significant. Generally the 'Flood Pulse' is considered vital for Tonle Sap ecosystem, species composition, and the internal nutrient cycle within the lake and its floodplain. Tonle Sap ecosystem productivity depends on nutrient availability, fish migrations and the level and duration of the floods (fluctuation between terrestrial and aquatic phases) which determine the floodplain structure and habitat diversity.

Changes in maximum flood level and volume (lowered) during flood season, water level fluctuation range (decreased) and flood depth and duration (generally shorter) will:

- Reduce natural decay and organic nutrients;
- Reduce input of sediments into Tonle Sap Lake and adversely affect the recycling of nutrients, threatening dry-season habitats, especially in areas with high fish productivity;
- Decrease habitat availability and fish spawning ground, following the decrease of inundated forests and grasslands in the floodplain; and

- Probably induce invasion of alien species e.g. *Mimosa pigra.*

As a very rough first estimate it could be reasoned that the reduction in flooded area, the reduced inflow and water and sediment and the change in flood duration and depth could result in an overall reduction of the primary productivity of the system of 20 to 30%. The increase in lake volume in the dry season and the increased inflow of nutrient may compensate part of these wet season losses.

Fish productivity is related to the availability of inundated habitats since the floodplain vegetation plays a crucial role by providing habitats, substrate areas, and food for fish and other aquatic organisms. As described in Chapter 2, fish catches in the area are directly related to maximum flood levels, sediment concentrations, duration of the flood (the longer the flood lasts the longer the fish can grow, provided there is enough food) and the characteristics of the flooded zone, grasslands playing an important role in nutrient cycling. With inundated grassland area decreasing with 3 to 10 %, (average and dry year), decreasing flood depth and duration and lower sediment inputs, fish production could reduce with up to 25% under the Definite Future scenario. Construction of the mainstream dams under the 20 Year Plan scenario would seriously affect the migratory white fish species. Up to 75% of the fish catch in Tonle Sap depends on fish that migrate to the deep pools found from Kratie to Siphandon and beyond for dry season refuge. As a consequence (white) fish production could fall to well below 50% of the production under the Baseline scenario.

With the global loss of wetlands, the Tonle Sap Lake and its relatively intact ecosystem processes are exceptionally important for global biodiversity. In a recent inventory, 885 species of floodplain plants and animals were found in the Tonle Sap. Over 200 species of plants have been found in the inundated forests and as many different fish species use this habitat as a feeding, breeding, and nursery ground. It is also vitally important for breeding colonies of large water birds.

Seasonally inundated grasslands are rich in species as well, they support a number of rare and endangered birds.

The marshes small pools and seasonal wetlands in the area are vital in maintaining breeding stocks of floodplain fish, including air-breathing species (e.g. gouramies, walking catfish), while in the wet season they function as breeding and nursery grounds for many fish species, the black fish. These wetlands are also important for almost all water birds in the Lower Mekong Basin.

The 2004 International Union for Conservation of Nature and Natural Resources (IUCN) Red List of Threatened Species mentions 197 species in Cambodia considered at risk of extinction, endangered, critically endangered, or vulnerable. Of the 197 species mentioned by IUCN, 24 are critically endangered, 39 are endangered, and 53 are vulnerable. Many of these are found in the Tonle Sap ecosystem: the Tonle Sap inundated forests form one of the most important breeding sites for at least 7 large waterbirds in Asia, including Globally Endangered Greater Adjutant *Leptoptilos dubius* and White-winged Duck *Cairina scutulata;* Globally Vulnerable Spot-billed Pelican *Pelecanus philippensis*; Milky Stork *Mycteria cinerea*, Lesser Adjutant *Leptoptilos javanicus*; Globally Near-threatened Oriental Darter *Anhinger melanogaster* and Painted Stork *Mycteria leucocephala.* Loss of inundated forest area, combined with a likely decrease in the ecosystems quality due to changing flood conditions, will further jeopardize the survival of these rare and endangered species.

Loss and degradation of the seasonally inundated grasslands threatens the survival of a number of bird species that are supported by this habitat: the Critically Endangered White-shouldered Ibis *Pseudibis davisoni*; 2 Globally Endangered species: Greater Adjutant *Leptoptilos dubius* and Bengal Florican *Houbaropsis bengalensis;* the Globally Vulnerable Spot-billed Pelican *Pelecanus philippensis*, the Greater Spotted Eagle *Aquila heliaca,* the Sarus Crane *Grus antigone,* the Manchurian Reed-warbler *Acrocephalus tangorum,* the Milky Stork *Mycteria cinerea,* the Lesser Adjutant *Leptoptilos javanicus*, and the Masked Finfoot *Heliopais personata*.

Also affected will be the Critically Endangered Siamese Crocodile *Crocodylus siamensis*; Hairy-nosed Otter, >5 commercial species of water snakes (caught & trade) and the endemic Tonle Sap watersnake *Enhydris longicauda*.

2.4 Consequences for the use of Timber and non-timber products

As described in Chapter 2.3.2 the natural floodplain vegetation is used for the collection of a variety of wood and non-wood forest products for a variety of uses. Some forest animals and their products are collected, including bee wax and honey, whereas birds are hunted for food, pets, and trade. Eggs are collected for consumption. Aquatic plants are collected for human consumption, as feed for farm animals, or for further cultivation (e.g., lotus).

Reduction of the flooded forest area or decrease in the quality of the ecosystem will negatively affect the use that local people can make of this resource for their sustenance.

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